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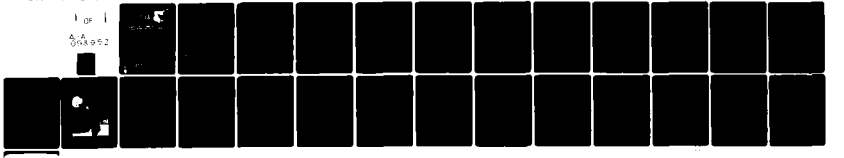

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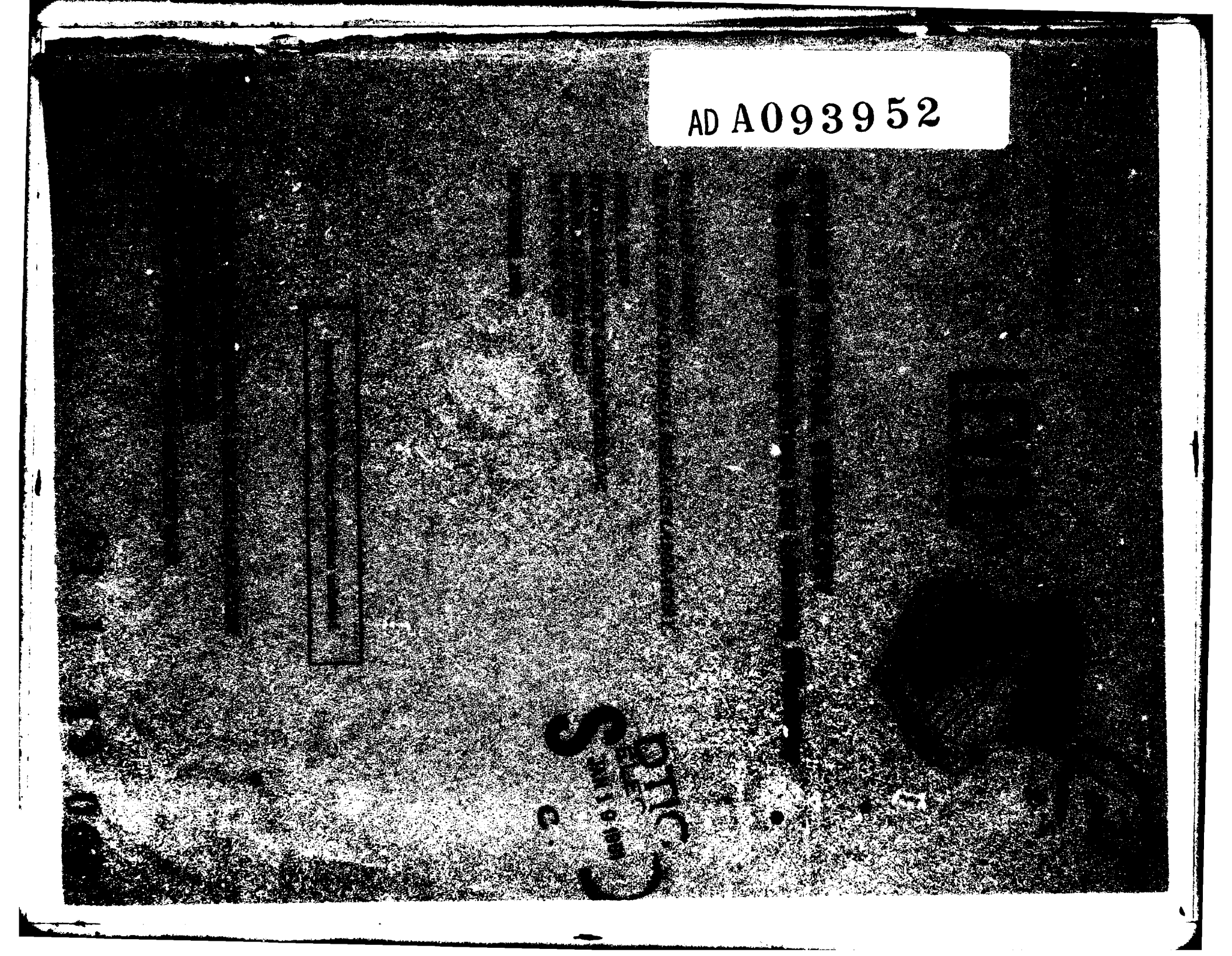

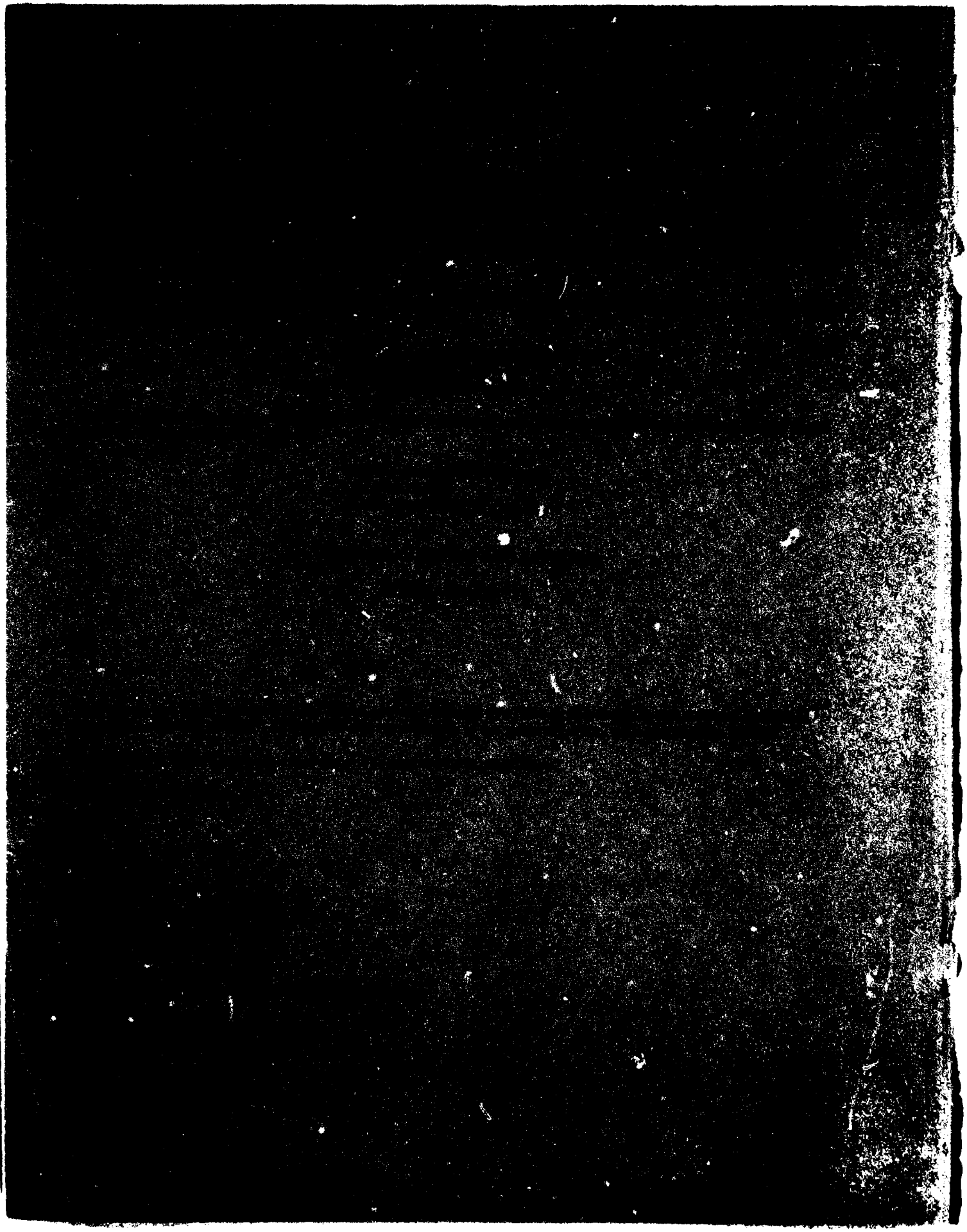

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A symbol association study was conducted to select from among three symbol sets a "best" set to convey tactical order-of-battle information on a CRT display to a pilot of a single-seat fighter aircraft. The three symbol sets were: (1) a set recommended by a panel of Air Force experts (SSC), (2) a set of pictorial symbols resembling the objects they were to represent, and (3) a set of geometric symbols with alphanumeric modifiers. The latter two symbol sets were composites based on symbols constructed by Air Force tactical pilots in an earlier experiment. (continued)

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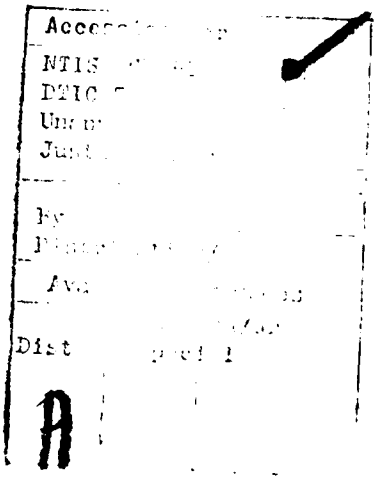
The criteria used to select the "best" symbols were: (1) fewest trials and least time to learn; (2) fastest recognition time for meaning; and (3) ease of display, i.e., fewest number of lines to generate the symbol. Each symbol set was viewed by ten separate college students with some military experience. After each symbol was presented, the subject picked its meaning from a list on a graphic display device driven by an IBM 370/155 computer which controlled the symbol presentation and calculated learning scores, i.e., recall times, trials to learn, etc. On the basis of the first two criteria, symbols from the pictorial set were selected for aircraft and naval vessels and objects/events pertaining to them. The remainder of the symbols were selected on the basis of ease of display and originated about equally from all sets.

PREFACE

This study was performed while one of the authors (W. Pearson) was assigned to the Systems Research Branch, Human Engineering Division, Wright-Patterson Air Force Base, Ohio, 45433. The work was performed in support of Project 7184, "Man-Machine Integration Technology", Task 718414, "Operator Workload Assessment", and performed between September, 1977 and June, 1978, under Air Force contract F33615-79-C-0503. Lt. Col. Robert D. O'Donnell was the task scientist and Mr. William H. Pearson was the Principal Investigator.

The authors wish to thank Dr. Donald A. Topmiller, Chief of the Systems Research Branch, for the inspiration, encouragement, and advice he tendered during the course of the study. The 370/155 IBM Computer used in this study was a Human Engineering Division facility under the management of Systems Research Branch at the time of the study.



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INTRODUCTION

Some military tactical display systems, both existing and planned, use symbols to convey tactical information to the system operator(s) about enemy and friendly aircraft, forces, vehicles, etc. Such systems include Tactical AWACS (existing) and Precision Location Strike System (planned). Parameters of the display and its purpose undoubtedly affect the type of symbols needed. What kind of symbols should be used on a tactical display? Are operator performance and mission effectiveness affected by the number and types of symbols used? No studies could be found to answer these questions.

The Joint Tactical Information Distribution System (JTIDS) is a secure, jam resistant, digital communication system for real-time command and control of combat operations. JTIDS uses Time Division Multiple Access to interconnect all system members into one common channel or network, for distribution of information. The pilot in a single-seat aircraft uses an electronic display device or CRT terminal to receive and transmit tactical information such as own aircraft position, other aircraft positions, threats, weather, etc. Because of competing panel space in the cockpit, this CRT or terminal will be small (probably 12 cm square). A set of compact symbols is needed to represent the tactical events/objects which can still be interpreted in a minimum time and can enhance tactical mission effectiveness.

One way of ascertaining whether one symbol is better than another is to compare how rapidly each can be associated with its referent. It is usually assumed that the fewer number of trials taken to learn the association between a symbol and what it symbolizes and the more quickly one responds, the better that symbol is for its intended purpose.

These symbols must satisfy several criteria simultaneously. The symbols must be maximally discriminable from one another so that they can be identified in minimum time and with minimum error. One can take advantage of population stereotypes, symbols which already have a certain meaning for

most of the pilot population or which have readily learned association value. Symbols should be geometrically simple and rapidly generated by electronic devices. Pilots typically do not like to operate in a "head-down" mode (looking down into the cockpit rather than outside) and hence they must be able to extract a maximum of information from the JTIDS display with short glances inside the cockpit while operating in a high threat environment "head-up" mode.

White and Wyrich (1975) developed and refined JTIDS information requirements for fighter aircraft to fit all major tactical missions. Because these missions might require tri-service interoperability, standardization of symbology was an immediate requirement. ASD/AES formed a Symbology Standardization Committee (SSC) in April 1976 to produce a symbol set to be used with a JTIDS display. The SSC recommended follow-on studies to attempt to optimize the symbol set for transfer of information to a pilot (Cassella, et al., 1977). These studies identified a number of symbols which can be used on a JTIDS display. Assuming that the symbols meet all technical display criteria (i.e., they are the correct size, have the correct contrast, have the correct line width, etc.), then do some symbols better represent the tactical object/event than others?

Several symbol sets were proposed for evaluation on the basis of the preceding suggested operator performance criteria. The set of symbols designed by the SSC was one candidate. In a previous study symbols for 42 different tactical objects/events were constructed, based on symbol preferences of pilots and college students (Pearson, et al., 1978). From these symbols two different sets of symbols were defined. One set was created with as many pictorial representations as possible--each symbol potentially different from each other symbol in the set. The other set was contrived, insofar as possible, with a basic symbol plus alphanumeric modifiers. Davis (1971) had recommended symbols differ strongly in shape.

This study was devised to test the usefulness of SSC vs. alphanumeric vs. pictorial symbols by comparing: (1) learning time for each symbol (i.e., response time on the final learning trial); (2) immediate recognition

measures (i.e., response time on the final testing trial); (3) the communicativeness of the symbol (Green and Pew, 1978); and (4) a 24-hour recall measure (i.e., the ability to write correctly the description of the symbol the following day on a take-home test form).

METHOD

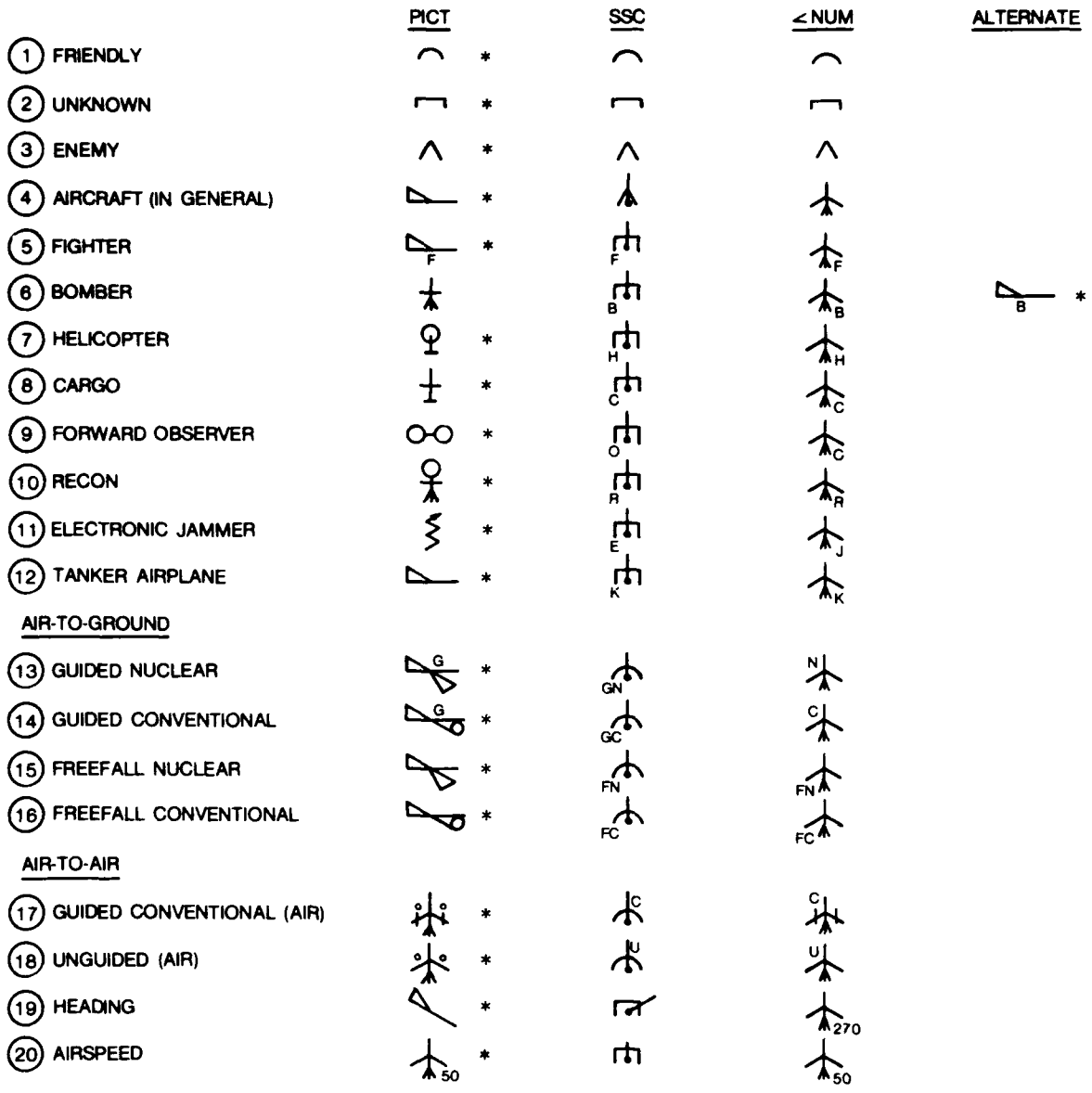
Design and Subjects

Each object/event to be symbolized (e.g., helicopter, unguided missile, ship, etc.) in the three symbol sets (i.e., SSC, alphanumeric, and pictorial) was compared on the four measures (i.e., learning time, recognition, communicativeness, and recall) to assess systematic differences on any of the measures which would favor the use of any one of the symbol sets. Symbols with fastest learning time, fastest recognition time, most communicativeness, and/or best 24-hour recall were desired.

The subjects were 30 college students and airmen chosen from a standing subject pool which had served in other military-sponsored research for approximately a year. Ten subjects were randomly assigned to each symbol set.

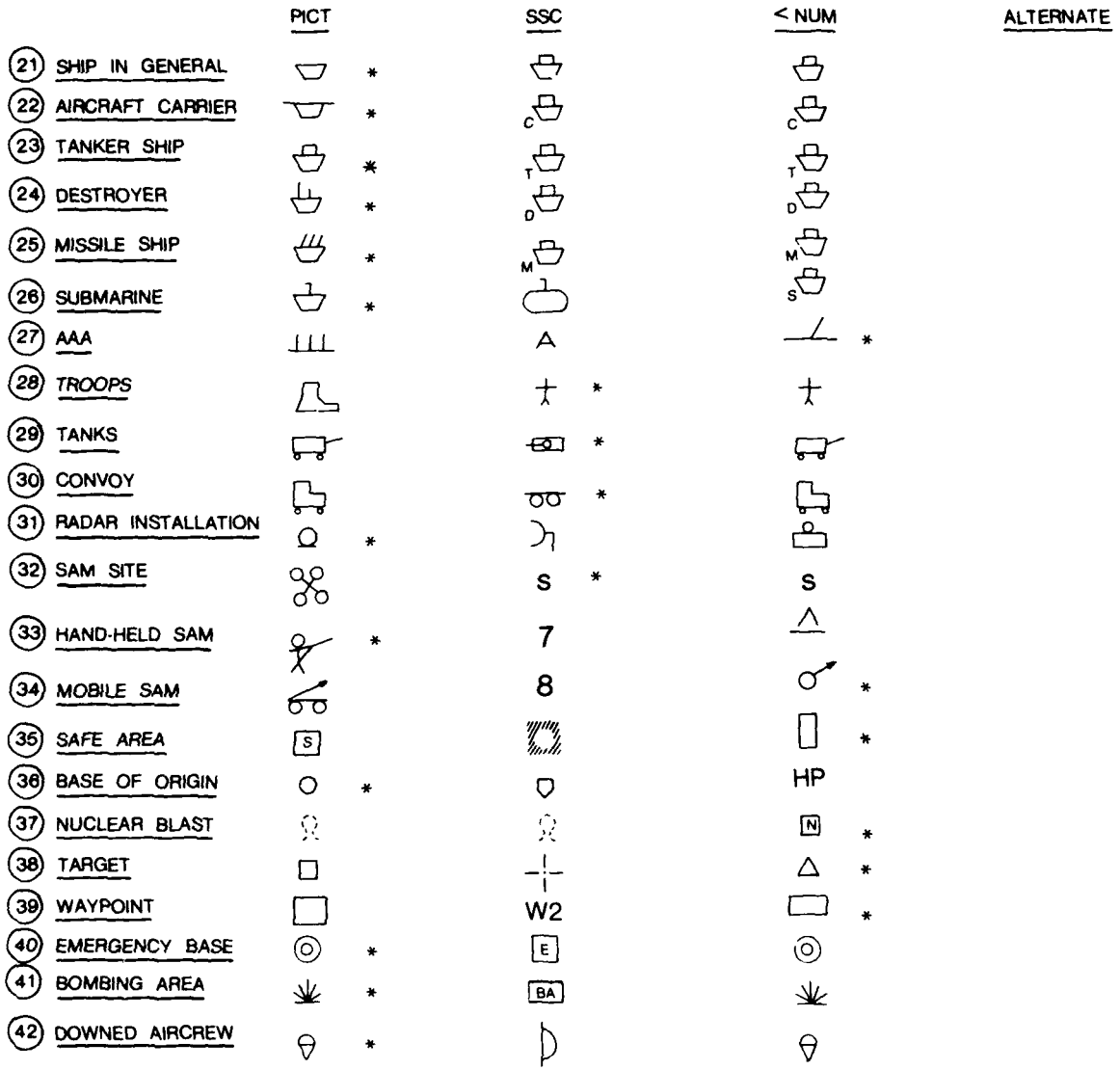
Materials and Apparatus

Each subject was serially presented 42 symbols (see Figure 1) from a given symbol set on an IBM 2250 display device. These symbols were stroke generated and presented so that the symbol luminance level was approximately 100 foot lamberts measured by Pritchard photometer. In order to reduce the contrast of the symbol and surround to 4:1, to simulate the cockpit environment, two flood lamps were mounted behind each subject and aimed at the CRT. The subjects used an IBM 2250 light pen to indicate their responses on the IBM 2250. The computer recorded the matching of the symbol with the title and the response time required.



* Recommended Symbol

Figure 1. Three sets of Symbols Used in Study (Pictorial, SSC, and Alphanumeric)



* Recommended Symbol

Figure 1. Three sets of Symbols Used in Study (Pictorial, SSC, and Alphanumeric) (Continued)

PROCEDURE

Learning Phase. Two subjects were run simultaneously to facilitate the experiment. They could not see each other's actions. After the subjects were seated at the IBM 2250 (see Figure 2), instructions were read to them for the learning phase. The IBM 2250 would then present the list of printed symbol descriptions along the right side of the display, and the experimenter would read a brief definition of the function of the symbols; i.e., tanker airplane--this aircraft carries fuel which it transfers to other aircraft in flight. Care was taken in devising the definitions (i.e., no symbol was referred to directly) so that no symbol or symbol set would benefit more than the others by offering clues to the design of the symbol being represented. The IBM 2250 would then present a "READY" message on the left side of the display and 3 seconds later a symbol would appear in its place. The subjects were instructed to light pen the correct answer as rapidly and as accurately as possible by using a wiping motion of the light pen. If they did not know which title was the correct one, they were asked to push a button which would cause an asterisk to appear beside the correct answer for 3 seconds after each symbol presentation. The "READY" message was then presented again, etc. The subjects were required to continue until they had completed three entirely correct trials. The order of the symbols was changed every trial to prevent serial learning effects.

Immediate Recognition Test Phase. During the immediate recognition phase, the instructions were the same, except that the symbols were presented in a 5-inch square on the right-hand side of the display and the printed descriptions appeared one at a time on the left. (See Figure 3.) How well the subject remembered the symbols was tested by how long it took him to recognize the symbol which matched the description. This task tests reverse association and evaluates the situation where the pilot has to scan the display for a certain type of symbol. The subjects matched the description with the appropriate symbol by means of the light pen; the recognition time scores were taken. The subjects were again required to continue until they had achieved three error-free trials in order to stabilize the recognition

Figure 2. IBM 2250 Display Device and Experimental Station

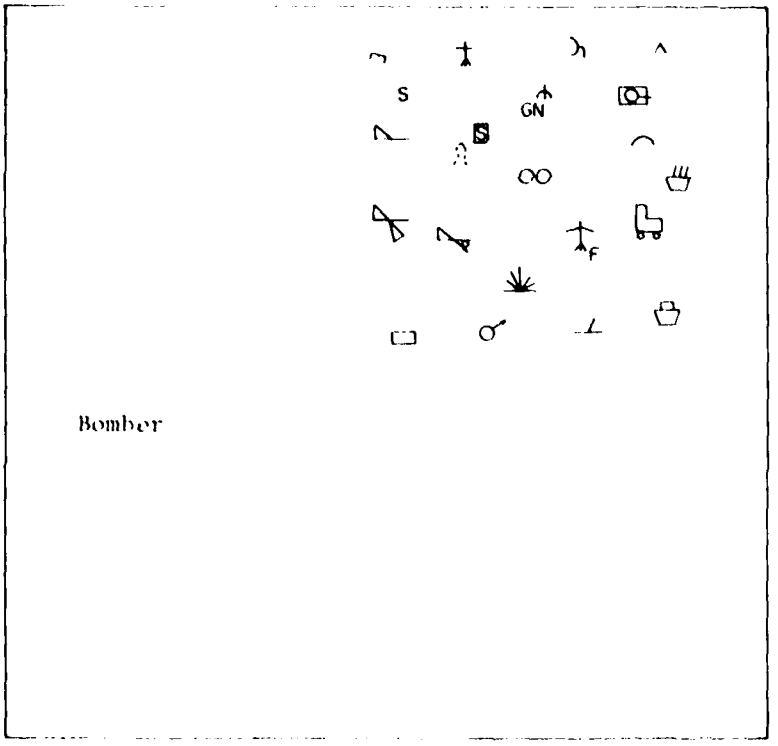


Figure 3. Appearance of IBM 2250 Display Device During Recognition Testing

times as much as possible. The time between learning and start of testing averaged 15 minutes. No control was kept of the subject's behavior between learning and start of testing.

24-Hour Take Home Test. Each subject received a two-page take home recall test. The symbols were listed in a randomized order with two blank spaces following each symbol. The subjects were to write the title of the symbol next to each picture and then to use a number between 0 and 1 to designate how appropriately they felt that the symbol represented the object/event symbolized. A 1 indicated the symbol was very representative, and a 0 indicated the symbol did not call the meaning to mind at all.

RESULTS

The differences among the symbol sets as a whole were evaluated by analysis of variance with respect to several dependent variables cited above. They differed significantly on average number of trials to learning criterion, with the SSC and pictorial symbol sets requiring 7.7 trials, while the alphanumeric set required 9.9 trials.

In addition to the four dependent measures discussed herein, there were others on which the symbol sets did not differ significantly. These were overall errors, requests for correct answers, overall response time on final trial, and number correct on first trial.

It was the intent of this study to compare the symbols on a symbol-by-symbol basis, if necessary, to make up a complete set. The symbols from each one of the three symbol sets were compared for each of the tactical events/objects being symbolized; i.e., all three symbols for aircraft, bombers, etc. Figure 4 gives the significance of the F-ratio for each one of these comparisons for the four dependent variables--learning time, immediate recognition time, communicativeness, and 24-hour recall. If the symbol from one symbol set was the "best"; i.e., easily interpretable, it should have significantly (or nearly significantly) lower learning, recognition, and recall times and greater communicativeness than the symbol from

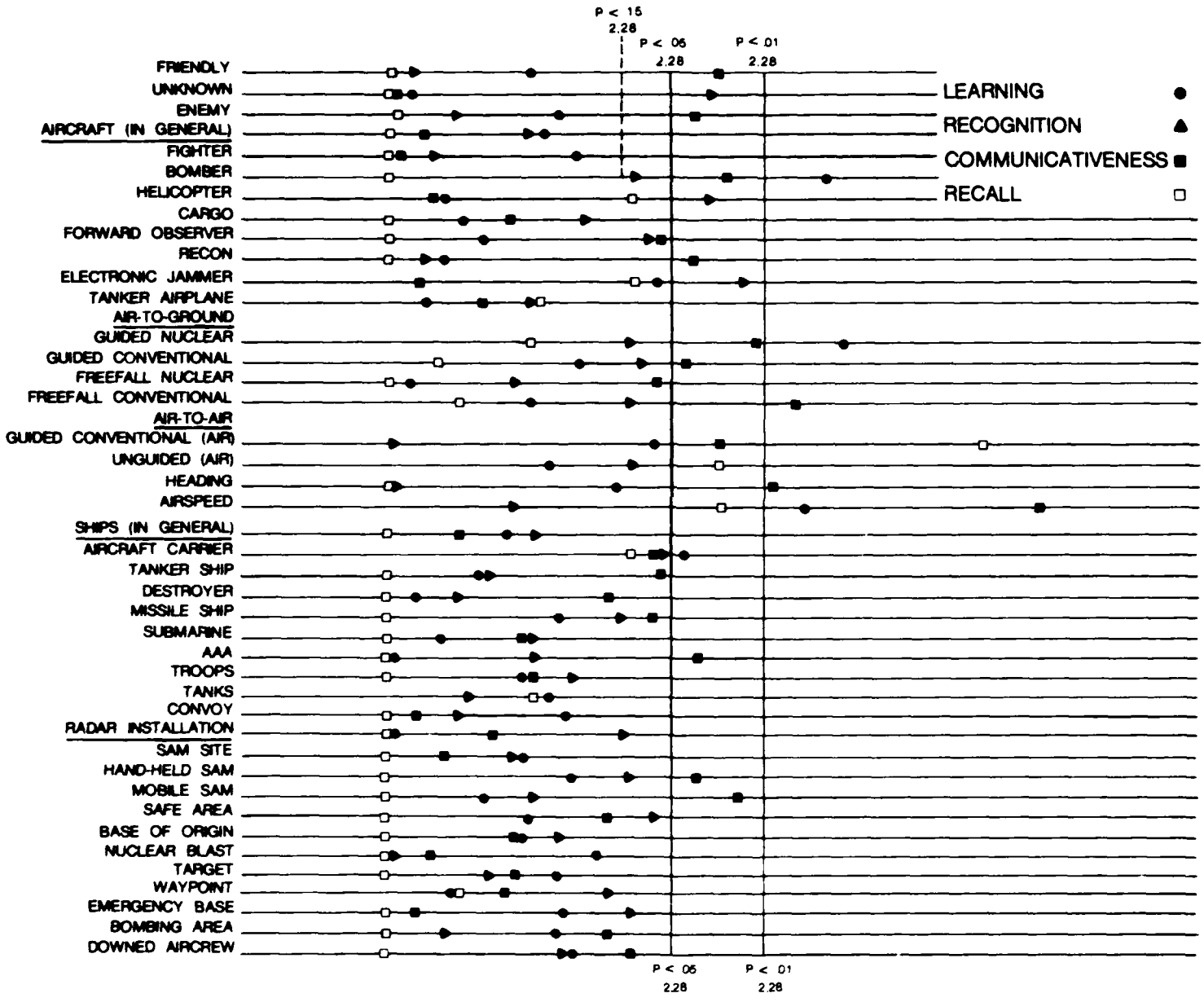


Figure 4. P Values for Four Dependent Variables for Each Symbol

the other two sets. Because of the essentially exploratory nature of this study, a criterion for significance was set much wider than usual ($p < .15$). Looking at Figure 4, one can see that, exclusive of aircraft, the following have at least one measure of the four significant--Guided Nuclear, Guided Conventional, Freefall Conventional, Guided (air-to-air), Unguided, Heading, Airspeed, Aircraft Carrier, and Hand-held SAM. In all but two of these, Guided and Freefall Conventional, the pictorial set is superior or equal to the others (Table 1 lists measures for the symbols for each of the three symbol sets).

For each symbol description comparison, no one symbol set was clearly or significantly better than the others. However, if one symbol set exhibited better scores on a significant number of a group of related symbols (binomial test, Siegel, 1956, pages 36-42), it would be preferred for those related symbols. Consider the nine symbol descriptions for types of aircraft (Table 2). If one picks the shortest learning time for each symbol, the alphanumeric set has the best for five of nine symbols, with pictorial best three times and SSC, one. These are not significant differences by the binomial test. The alphanumeric symbol for Bomber is learned significantly more quickly than the others. For immediate recognition, the pictorial set has the shortest reaction time in seven of the nine aircraft categories, which would happen only 25 times out of a thousand ($p \leq .025$, Parzen, 1960, page 53). For communicativeness, the alphanumeric set was best seven out of nine times ($p \leq .025$). For 24-hour recall, the SSC symbols were significantly poorer, the other two not being significantly different.

DISCUSSION

The interpretation of these data is not completely straightforward, but it is the authors' opinion that a choice among the symbol sets can be made. The criteria are twofold: (1) because a group of like symbols, i.e., aircraft, should be from the same set, the overall merit of any symbol set should be ascertained over that group of symbols, and (2) where no significant differences exist, the simplest symbol to display will be chosen. Simplest means requiring the fewest number of lines and/or circles needed

TABLE 1. FIGURE OF MERIT SCORES FOR SYMBOLS DIFFERING SIGNIFICNATLY ON DEPENDENT MEASURES

	Dependent Measures	SSC	Picture	Number
Heading	Communicativeness	.57	.81	.99
	Learning	357.50	293.10	300.40
Airspeed	Learning	466.40	282.00	335.90
	Communicativeness	.32	.94	1.00
	Recall	.70	1.00	1.00
Aircraft Carrier	Learning	439.20	325.00	492.40
	Recognition	355.90	262.60	473.30
	Communicativeness	.83	.91	.99
	Recall	.80	1.00	1.00
Handheld SAM	Communicativeness	.50	.93	.72
	Recognition	325.60	227.00	328.80
Airplanes				
Bomber	Learning	350.00	442.70	320.90
	Recognition	368.80	238.40	438.30
	Communicativeness	.91	.76	1.00
Helicopter	Recognition	311.30	258.10	512.80
	Recall	.80	1.00	1.00
Electronic Jammer	Learning	392.60	283.00	325.10
	Recognition	544.20	225.50	379.10
	Recall	.80	1.00	1.00
Stores--Air-to-Ground				
Guided Nuclear	Learning	459.50	399.20	717.60
	Communicativeness	.53	.76	.94
	Recognition	388.10	418.30	608.50
Guided Conventional	Communicativeness	.52	.72	.89
	Recognition	435.50	500.50	659.50
Freefall Conventional	Communicativeness	.51	.67	.96
	Recognition	416.50	602.80	481.00

TABLE 1. FIGURE OF MERIT SCORES FOR SYMBOLS DIFFERING SIGNIFICNATLY ON DEPENDENT MEASURES (continued)

	Dependent Measures	SSC	Picture	Number
Stores--Air-to-Air				
Guided	Recall	.30	1.00	.80
Conventional	Communicativeness	.45	.69	.88
	Learning	492.20	349.40	485.80
Unguided	Communicativeness	.46	.68	.89
	Recognition	519.40	413.60	658.40

NOTE: Learning Scores are in Milliseconds

Recognition Time is in Milliseconds

Communicativeness is on Scale of 1.0 to 0.0

Recall Scores are in Percent Correct

TABLE 2. COMPARISONS OF DEPENDENT MEASURES FOR THE NINE TYPES OF AIRCRAFT SYMBOLS

	SSC	Picture	Number
Aircraft Learning Time:			
Aircraft (gen.)	388.0	293.6	274.0
Fighter	383.3	324.3	312.3
Bomber	350.0	442.7	320.9
Helicopter	326.8	339.5	314.8
Cargo	412.0	363.3	401.3
Fwd. Observer	246.8	301.5	319.2
Recon.	365.5	380.8	333.9
Elec. Jammer	392.6	283.0	325.1
Tanker	338.1	372.8	347.3
Aircraft Recognition Time:			
Aircraft (gen.)	317.3	356.6	431.0
Fighter	266.1	274.6	265.9
Bomber	368.8	238.4	438.3
Helicopter	311.3	258.1	512.8
Cargo	322.7	273.7	415.0
Fwd. Observer	311.1	255.2	453.7
Recon.	273.8	257.4	293.3
Elec. Jammer	544.2	255.5	379.1
Tanker	498.6	395.6	479.2
Communicativeness:			
Aircraft (gen.)	.87	.87	1.00
Fighter	.93	.92	.90
Bomber	.91	.76	1.00
Helicopter	.81	.75	.85
Cargo	.94	.78	.90
Fwd. Observer	.82	.75	1.00
Recon.	.92	.83	1.00
Elec. Jammer	.82	.85	.90
Tanker	.72	.77	.87

TABLE 2. COMPARISONS OF DEPENDENT MEASURES FOR THE NINE TYPES OF AIRCRAFT SYMBOLS (continued)

	SSC	Picture	Number
Recall:			
Aircraft (gen.)	1.00	1.00	1.00
Fighter	1.00	1.00	1.00
Bomber	1.00	1.00	1.00
Helicopter	.80	1.00	1.00
Cargo	1.00	1.00	1.00
Fwd. Observer	1.00	1.00	1.00
Recon.	1.00	1.00	1.00
Elec. Jammer	.80	1.00	1.00
Tanker	.90	1.00	1.00

to generate the symbols on the JTIDS display. It is assumed that a circle generator exists in the hardware generating the display.

One group of symbols which should be considered as a whole is the aircraft grouping--Aircraft-in-general, Fighter, Bomber, etc. The SSC and alphanumeric symbol set members are both instances of variations on a basic symbol while the members of the pictorial set are different from one another. Learning scores indicate only that the symbol for Bomber should be either alphanumeric or SSC. Both these two have the alphanumeric modifier "B." Immediate recognition scores significantly favor the pictorial symbol set. Twenty-four-hour recall scores merely contraindicate the SSC symbol set. Communicativeness scores significantly favor the alphanumeric but, because they are opinion scores and taken 24 hours after experimentation, they are not regarded as a primary source of data. With the exception of Bomber, the authors recommend that aircraft be pictorial symbols and Bomber should look like Fighter only with a "B" below (see Figure 1). At the time of this publication this is an untested symbol; however, the authors are convinced that this symbol would best meet the advantages of both sets and yet fall into the pattern of the other aircraft symbols.

A related problem exists on the Stores, Air-to-Ground and Air-to-Air; they are indicated as modifications of an aircraft. Significant communicativeness scores favor the alphanumeric while the more objective scores seem to favor the pictorial. Because the pictorial set is favored for aircraft, the pictorial set is also recommended for Stores. Similarly, the pictorial set is also recommended for Heading and Airspeed.

The last group of symbols to be discussed are the symbols representing the various Ships. Both the SSC and alphanumeric sets consist of a basic symbol plus alphanumeric modifiers while the members of the pictorial symbol set are different from one another. The only significant difference among the group is for Aircraft Carrier, the pictorial set having better learning scores than the others. Because the symbols should be internally consistent in make-up, the pictorial symbol set is recommended for all Ship symbols. The pictorial symbols are also easier to generate electronically.

One other difference among the symbols was found to be significant. The pictorial set symbol for Hand-held SAM has significantly better scores than the symbol from the other two sets. The other SAM symbols; i.e., Mobile SAM and SAM site, are not necessarily related to each other and will not be recommended on the basis of the above results. The other differences are not significant and cannot guide the choice of symbol.

The other criterion is the simplicity of the symbol. On the basis of having the fewest lines necessary for electronically generating the symbol, the SSC symbol is recommended for Troops, Tanks, Convoy, and SAM site. The pictorial symbol is recommended for Radar Installation, Base of Origin, Emergency Base, Bombing Area, and Downed Aircrew. The alphanumeric symbol is recommended for Mobile SAM, Safe Area, Nuclear Blast, Target, AAA, and Waypoint. Again, the authors stress the assumption that a capability for circle generation is incorporated into the hardware.

CONCLUSIONS AND RECOMMENDATIONS

A "best" set of 42 symbols for tactical objects/events was recommended to furnish order-of-battle information to the pilot of an operational tactical aircraft. Symbol usability was enhanced by minimizing trials to learn, learning and recognition times, and number of lines in the symbol.

The "best" symbols are indicated by asterisks in Figure 1. It will be noted that most of these symbols originated from the pictorial symbol set, the choice of a pictorial symbol for Aircraft and Boat precipitated the considerable use of the pictorial set. Other "best" symbols were about equally divided among the three-symbol set. These results are consistent with Davis' admonishment that the symbols "should differ strongly in shape" (Reference 2, page 21).

It cannot be too strongly emphasized that these recommendations depend on meeting a few assumptions about the display. If these assumptions are not met, the recommendations can be completely vitiated. A strokewritten

display is assumed; oblique lines are not well rendered in raster scan format. A straight up and down orientation is assumed for all symbols except aircraft. Direction of movement of aircraft is indicated by orientation. Alphabetic symbols take longer to be interpreted, also, when rotated.

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